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Building a geocellular model of the sedimentary column at Rousse CO_2 geological storage site (Aquitaine, France) as a tool to evaluate a theorical maximum injection pressure.

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Abstract

TOTAL conducts the Lacq CO_2 pilot, the first French pilot to demonstrate the technical feasibility and reliability of an integrated CO_2 capture, transportation, injection and storage scheme from a boiler at a 1/10th reduced scale of an industrial project.
The geological storage reservoir selected is a depleted reservoir of Rousse field, an isolated satellite of the Meillon St-Faust gas field (Aquitaine, France). A geological cellular model of the sedimentary pile above the storage reservoir was built as a tool to model and quantify a theoretical maximum CO_2 injection pressure and potential CO_2 migration into the sediments if this maximum pressure is exceeded.

CO_2 Geological Storage, Pyrenean Foothills, Geomodeling, Carbonate Reservoir, Mature Field

1. Introduction

Rousse's structure gas condensate reservoirs in Mano and Meillon Dolomites were discovered in 1967, with virgin pressure of 480 bars at a depth of 4200 meters below mean sea level. They are two disconnected and superimposed Jurassic dolomitic reservoirs and today Mano upper reservoir is produced through well Rousse-1 and Meillon lower reservoir through well Rousse-3.

If and when proper authorizations are given, the injection will be done in the Mano Dolomite converting Rousse-1 well into a CO_2 injector. Current pressure in Mano reservoir is around 30 bars. CO_2 injection, limited to two years, is expected to increase reservoir pressure back to 70 bars. As such, the final CO_2 injection pressure will be significantly below both the initial gas pressure of 480 bars and the hydrostatic pressure of 420 bars. Due to this

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water pressure barrier, no CO_2 gas flow from the storage reservoirs into geological sediments is physically possible. However, for larger scale CO_2 geological storage projects, the determination of the maximum CO_2 injection pressure to avoid any CO_2 migration out of the storage reservoir is essential. This integrity assessment combines capillary, geochemical and geomechanical evaluations and interactions between these. The modelled area covers 100 km^2, is 5 kilometers thick and is constrained by 23 gas wells. Seismic interpretation of horizons and faults support the model.

The model represents with the best available knowledge of the principal heterogeneities, as faults and unconformities, distributed in a relatively complex structural area in Pyrenean foothills where three main tectonic and sedimentary phases are expressed. Dynamic flow models were run with ECLIPSE to validate connectivity between the heterogeneities, including geological heterogeneities (faults and unconformities) and wells.

2. Geological context of Rousse [1]

The Aquitain basin is located in the southwest of France, between the Gironde Arch in the north and the Pyrenean Mountain Chain in the south [1]. This 35000 km2 area is subdivided into four sub-basins: the Parentis, Adour-Arzacq, Tarbes and Comminges areas (Fig 1).

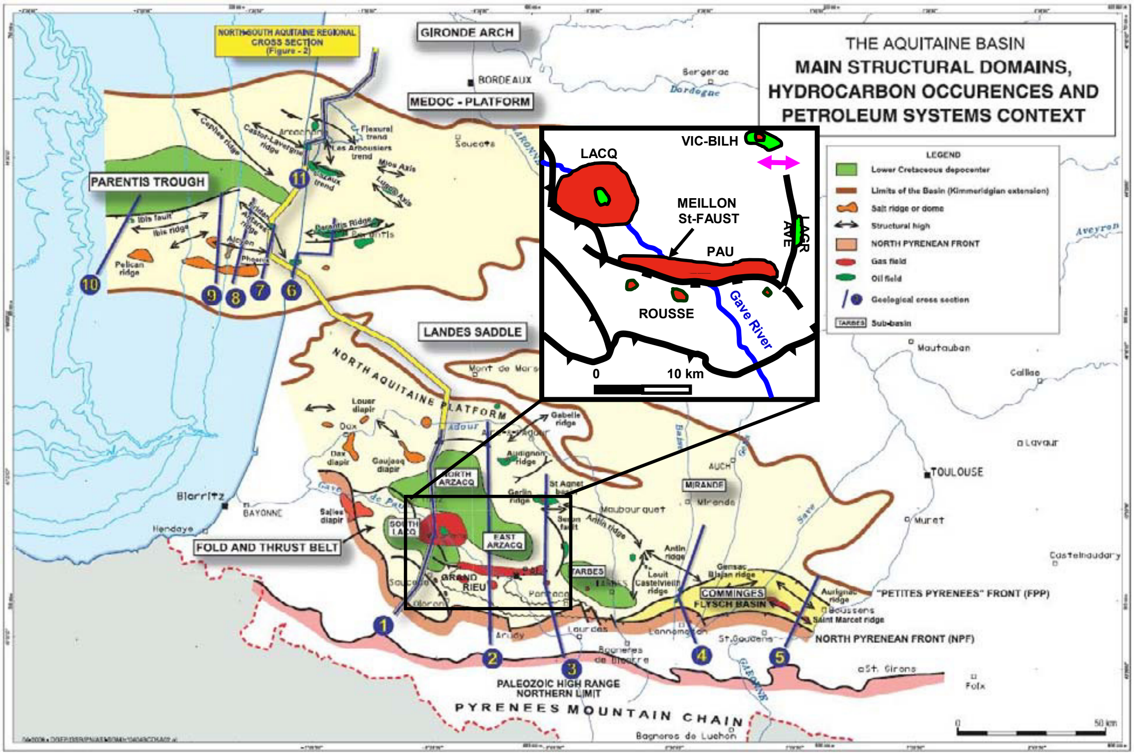

Fig 1 Regional location of Rousse [1]

The lozenge shape of these depo-centers is related to the Hercynian tectonic framework of the Paleozoïc basement, reactivated during Early Cretaceous rifting after a carbonate platform period during Jurassic. This rift phase aborted at the end of the Albian, prior to the development of an oceanic crust, in response to the beginning of the subduction of the Iberian plate under the European one (Fig 2). During the Upper Cretaceous, a continued subduction led to the creation of northwards-migrating flexural basins. In the Eocene, a paroxysmal phase of compression was responsible for the uplift of the Pyrenean Mountain Chain and for the thin-skinned deformation of the foreland basin. The resulting structure is limited to the south by the internal core of the chain and to the north by the leading edge of the fold-and-thrust belt.

Our interest zone corresponds to the Adour-Arzacq sub-basin (Fig 1) with a gas trend [2] on the south limit where from west to east the deep giant Lacq (disc. 1951, 260Gm3 gas – 9.2TCF), Meillon (disc. 1965, 65Gm3 – 2.3TCF) fields are located. An oil trend correspond northerly with the edges of the foreland basin and a succession of NW-SE salt ridges whit some discoveries in the 1970's. Laterally to the Lacq and Meillon St-Faust area, several smaller sized gas field with accumulations ranging from 110 to 250BCF (Ucha, Lacommande, Cassourat and Rousse) were also discovered.

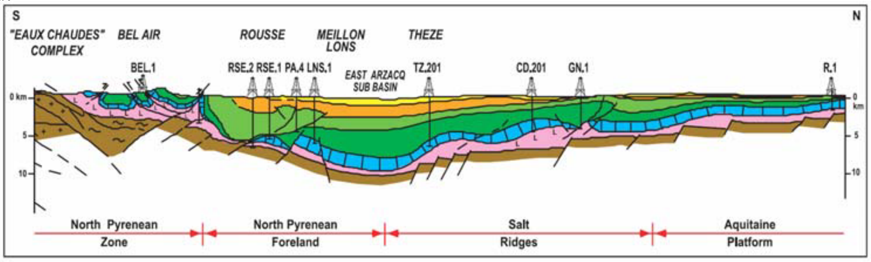

Fig 2 Regional cross section including Rousse [1]

3. The Rousse gas structure

The Rousse's structure area is about 4km^2 and the distance between Rousse and Meillon St-Faust fields is two kilometers. The structure is a good summary of the regional context with a location at the limit of the north foreland, dynamically isolated from Meillon St-Faust which is the south limit of the Arzacq basin. The thickness of Upper Cretaceous flysch and similar Tertiary sediments is high on Rousse. The figure 3 shows a northern decreasing of Upper flysch Cretaceous (passage to a platform) and Lower Tertiary compensed by increasing of Oligo-Miocene due to a northern displacement of syntectonic deposits basins.

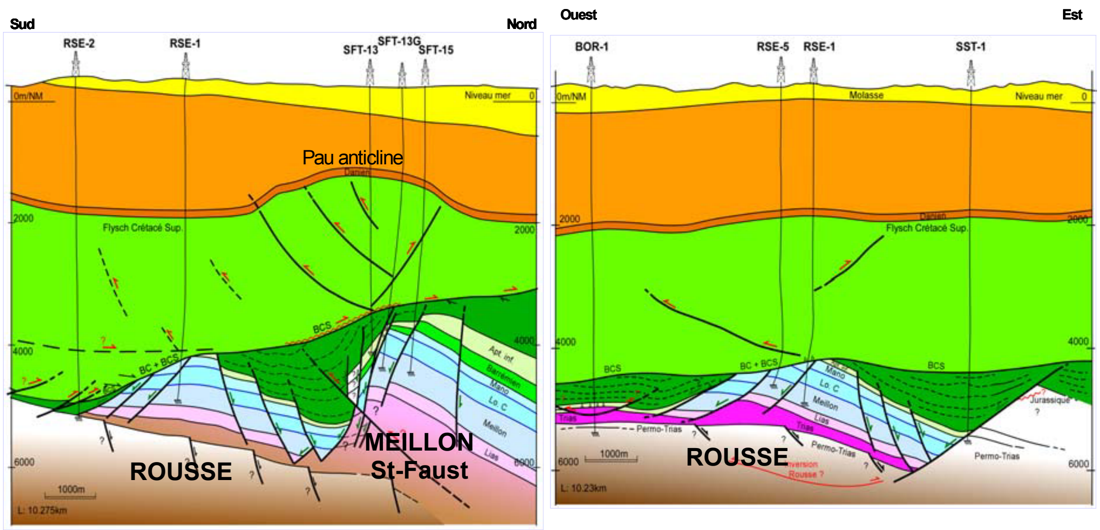

Fig 3 Cross sections trough Rousse area

Four structural phases are superimposed: a carbonated Jurassic platform deposition, an Albo-Aptian syn-rifting tectonic (Jurassic tilted and eroded then thick basinal sedimentation), an Upper Cretaceous erosive discontinuity with a thick flysch deposition and finally a Tertiary compressive sedimentation and tectonic. The structure overlying the traps, known as the Pau anticline, is understood to be the pop-up structure induced by a slight thrust movement from the south initiated by the North Pyrenean Frontal Overthrust, some 10-15 kilometers to the south (Fig 2). It has propagated towards the north by bedding-plane slip within the Albo-Aptian series and the base of the Upper Cretaceous Flysch then was deflected upwards, both due to a facies change to the north for the Upper-cretaceous (see above) and is response to the underlying steep wall of rigid Jurassic carbonates of the Meillon St-Faust field which acted as a stop.

Rousse area is limited by normal faults. The disconnection with the northern Meillon St-Faust structure appears to be the result of the Albian synrift extension. The quality of gas is different between Rousse (more C1, no H2S, rich in condensates) and Meillon St-Faust. These two fields produce gas from two reservoirs: upper Mano and lower Meillon dolomites. The petrophsical characteristics are rather poor (2 to 4% matrix porosity for the Mano and 4 to 8% for the Meillon dolomites). For these formations, effective permeability is primarily due to fractures and vugs (due to secondary diagenesis and abundant in Meillon dolomite), allowing for a good productivity of the wells. This effect is important in Rousse reservoirs. Different schemes exist as explanation for the Rousse's structure: normal faulting due to the Albo-Aptian or salty activity at the end of Jurassic and Barremian. The first one is more in accord with the geophysical and geological available data and is the base of the geocellular model.

4. Geocellular model construction

The objective of the model is to be a tool to perform Risk Analysis of the CO_2 geological storage system. One key issue for any geological storage site is to establish a maximum CO_2 injection pressure in the host reservoirs before any leakage of CO_2 out of the reservoir takes place.

In the case of Rousse CO_2 geological storage, CO_2 migration could hypothecally eventually takes place:

- through the sedimentary column
- through geological heterogeneities as faults of the Pau anticline and Base Cretaceous unconformity
- through wells
- within aquifers, as Danien aquifer.

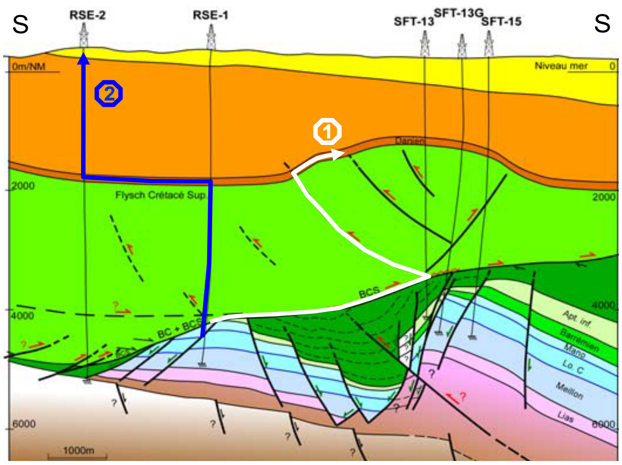

Fig 4 Example of two hypothetical leakage paths from Rousse reservoir

Figure 4 illustrates two hypothetical leakage pathways coupling wells, aquifers, faults and the Base Cretaceous unconformity. In order to cover these possible leakage pathways, the geocellular model includes:

- the Rousse and Meillon St-Faust reservoirs
- all the sedimentary column series above up to the surface
- all the potential aquifers (Infra Molasse Oligo-Miocene, Intra tertiary, Base Tertiary, Aptian (2007 BRGM study for TOTAL) or other hydrocarbon reservoirs present in this column (Base Upper Cretaceous, Base Tertiary along the Pau anticline).
- the main unconformities as faults or discordances as potential drains

The main challenge is to reconcile data from different sources and at different scale and to model them. For example the base of Tertiary is outcropping south of Rousse and some maps are a merge between outcrops and seismic. We want a metric scale layering for the Jurassic (Fig 5) but we will have very thick cells in the Upper Cretaceous. Building a model with a total thickness of 6000 meters and with a maximum of details is not so frequent. It is necessary to simplify the geometry.

4.1. General workflow

The modeling was done with PETREL, a tool which permits to have in the same data base the wells (logs, correlations), the seismic (geometries) and the external data as geological maps. With PETREL it is possible to integrate together and user friendly these data and build the gridded model.

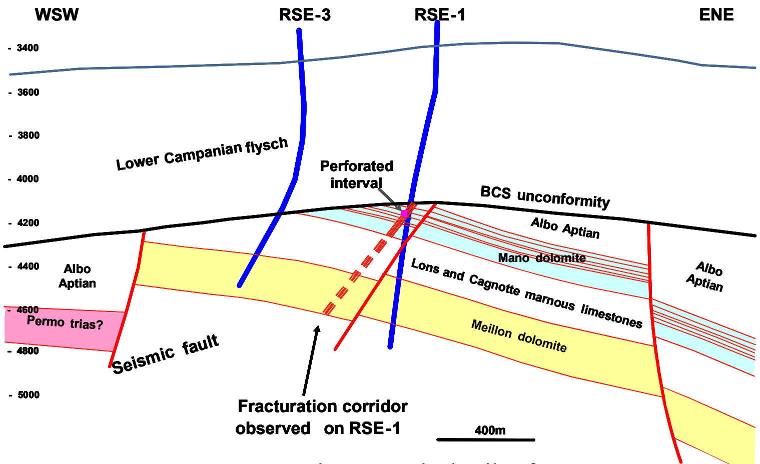

Fig 5 Jurassic details of Rousse

4.2. The faults

Modeling the faults is the first step; because of they give pillar for gridding in PETREL. As we want have the possibility represent vertical flows due to faults, specific zone property where a value is attributed to the cells representing faults.

Rousse is a triangular and faulted structure with main accidents on the limits and inside where three main compartments are mapped from wells, dynamic and seismic sources. The difficulty is to represent these faults in the model because of the small size of the compartments and the elongated form of the structure. The distance between these faults with important dip is not very important in the Jurassic and above in the Cretaceous and Tertiary they don't exist and we can't conserve the dip without obtain their crossing. Regarding the size of the model's cells (100 meters) it appears that the horizontal displacement of the Rousse's faults in Mano or Meillon is inferior to this distance and besides the main uncertainties for their location, the decision is to conserve vertical all the Rousse's faults. The faults are not represented with determinist volume. Indexation fault by fault is given to all the cells along the faults in limestones between Mano and Meillon dolomites and in Lower Cretaceous.

Northward, the Meillon St-Faust structure is limited on South with a main normal faulting system. Above, but disconnected, an incurved fault traduces the results of the Alpine compressions on cretaceous flysch (Fig 3, left). These two accidents are not exactly in the same plane, but it is easy to model two neighboring faults for the same problems of pillars. More, here we want to be able to model an hypothetic flux along the fault in Upper Cretaceous and tertiary. By simplification, the two faults are integrated in a same object which is here a column of cells. The disconnection is done with the same zone property : a different index is given to the part of the fault in Jurassic, the part of fault in Albo-Aptian, the part of the fault in Upper Cretaceous and the part of the fault in Tertiary. In ECLIPSE, by activation of desired part of faults it is possible to create communication between elements of the model.

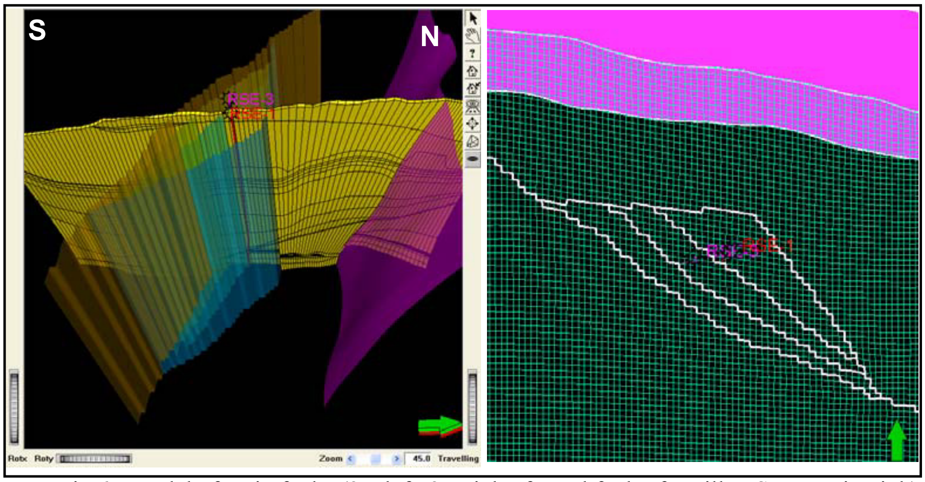

Fig 6: Model of main faults (3D left, 2D right, frontal fault of Meillon St-Faust in pink)

The problem of antithetic faults is resolved in ECLIPSE (see 5.1).

4.3. Geometry

The grid covers an 8 kilometers east-west and 10 kilometers north-south area, centered on Rousse. The horizons mapped are the topography and the main seismic markers : Base Molasse Oligo-Miocene, Base Tertiary, Upper and Lower Cretaceous.

The zones between correspond to the different elements of the sedimentary column including aquifers and intermediate covers. They are introduced as isopach maps which are built with the regional available wells and seismic data.

The Base of Upper Cretaceous is a regional discontinuity. On the structure of Rousse, this unconformity is directly in contact with the Mano (Fig 5). To evaluate a possible leak along BCS, a volume is attributed to it giving a constant thick of some meters.

A more detailed layering is introduced for the reservoir Mano, where the CO_2 will be injected. Six ten-meters thick layers permit to distinguish the heterogeneities of this dolomite based on a vertical distribution of oolitic and brecciated levels seen in the wells and observed on regionally. The final grid includes thirty levels and 206000 cells. The *Zonation property* from PETREL is illustrated on the figure 6. All the zones built as asked above are clearly defined as well as the different segments of faults. This property is exported as a FLUXNUM in ECLIPSE.

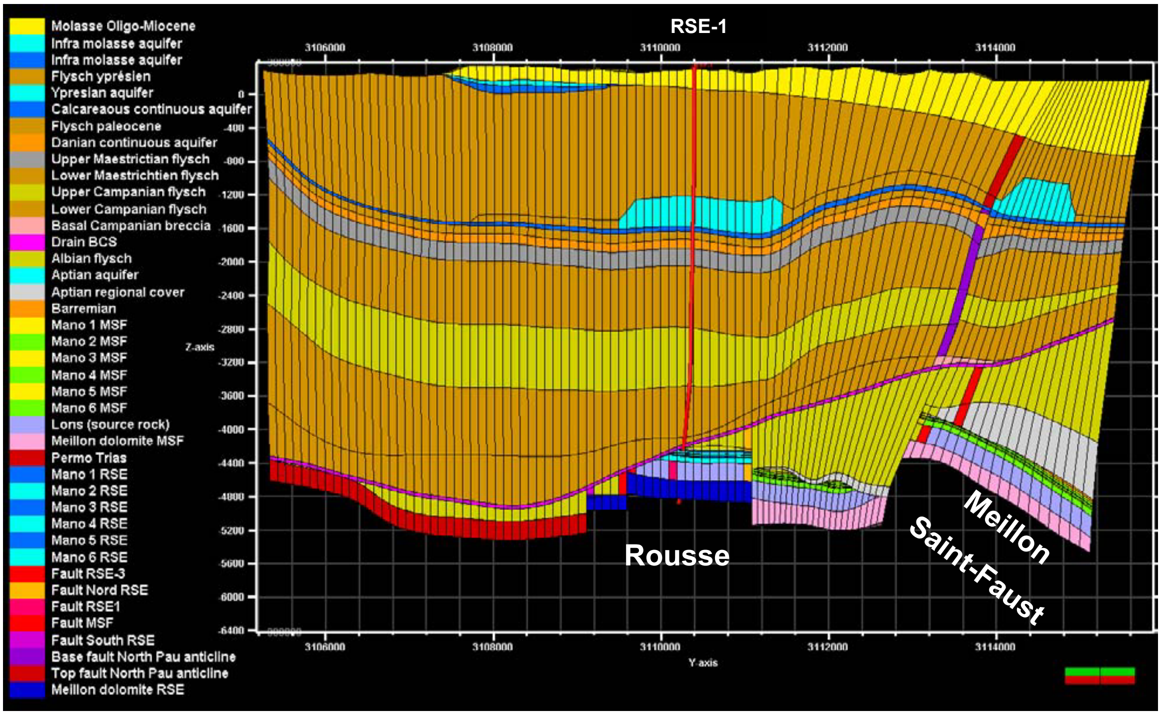

Fig 6 North-South cross section in the model

4.4. Properties

The full model is populated in net to gross, porosity, permeability. No cut-off is applied and the distribution of properties is issued of TOTAL's regional databases.

5. Connectivity tests using the geocellular model

A reservoir model was set up in order to perform connectivity tests in the geocellular model. The objective is to ensure that the geological heterogeneities can hypothetically connect each other and transport CO_2 and other fluids.

These connectivity tests are not built to reproduce possible CO_2 migration:

- the processes that would hypothetically lead to the alteration of the sealing efficiency of faults and unconformities (as temperature, stress, geochemistry) are not reviewed
- the heterogeneities are initialized with a permeability as high as 1 Darcy, which is not expected to happen in any scenario on such thicknesses.

The reservoir model includes:

- the geocellular grid and the petrophysical properties presented above
- a pressure initialization based on the formation water density
- a continuous CO_2 injection into Rousse Mano reservoir with a rate of 1 MSm^3/day for 1 century without any pressure limitation, leading to pressure build up much higher than initial gas pressure within Rousse reservoir

A first connectivity test was set up in order to reproduce a migration path through the Base Cretaceous unconformity and the faults of the Pau anticline. This scenario is sketched as migration ① in figure 4.

The difficulty to model such a scenario is due to the pillar gridding process within PETREL. As illustrated on figure 7, the only fault of the anticline constraining the pillar gridding process is the northern one. The southern or intermediate faults, as displayed on figure 3, constrain the various horizons but are not used within the pillar gridding process. As a consequence, there is no match between specific model cells and these southern faults. Hence, it is not possible to assign directly a high permeability value to specific cells to model a flow within such heterogeneities.

Various options were tested in order to reproduce a CO_2 migration though a highly conductive southern fault of the Pau anticline, as various refinements of the layering together with the definition of a stair step fault.

In order to achieve satisfactory migration path, a hybrid grid was built (figure 8), made of

- the geocellular model as defined in previous sections
- an additional row of cells modeling a southern fault of the anticline.

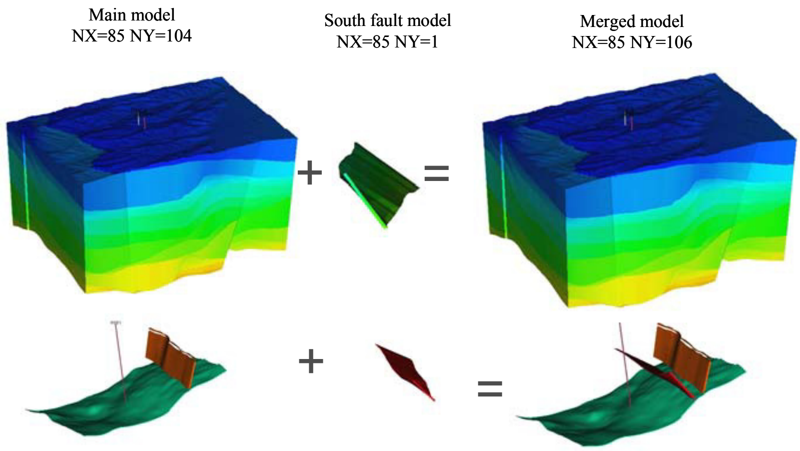

Figure 8: Construction of a hybrid grid to incorporate a fault with an alternative pillar griddind strategy. Model view at the top and view of well, Base Cretaceous and anticline faults only at the bottom

As the hybrid model contain cells that are geometrically neighbors even if their I, J, K indices are not, the connectivity between the added southern fault and the aquifers and Base Cretaceous has to be imposed by defining non neighbor connections in the model.

This approach enables to model gas flow within the various faults of the anticline, assuming these are conductive.

Moreover, in order to model hypothetical water and gas flows connected to leaking wellbores (due to cement degradation, or flow within annulus ...), proper tests were performed using cylindrical local grid refinements.

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